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LONG TERM STRENGTH OF CHOPPED GLASS REINFORCED PLASTICS IN WATER

by

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Summary

Data are presented on the long term strength of chopped strand mat glass reinforced polyester resin in water under both static and fatigue loading. The results may be described by a single semi-empirical equation which may be useful for long term extrapolation, but detailed understanding of the failure mechanism will require further study.

1. Introduction

This is an interim report describing the results to date on long term tests of a typical glass reinforced plastic (GRP) composed of chopped strand mat glass (CSM) in an orthophthalic polyester resin. Various combinations of wet and dry conditions and static and fatigue loading are covered and a few tests in dilute acid are also reported. Together these encompass the majority of conditions likely to be encountered by high-volume-production, commercial GRP, and when completed, these test should provide a sound basis for design. A review of previous work reported in the literature (which is not extensive) will be deferred to the final report.

2. Experimental

Sheets nominally 5 mm thick were prepared by hand lay-up using six plies of Pilkington's Supremat (450 g/m^2) and Crystic 189 LV resin containing 2% catalyst M (MEK peroxide) and 0.5% accelerator E. Glass and resin were weighed in the ratio two parts resin to one of glass which resulted in a final volume fraction of approx 20% fibre. Fibre volume fractions of individual specimens were measured by burning off the resin but in practice it was found that normalising the failure stresses to constant volume fractions did little to improve the scatter of results, presumably because of variations within the specimen and the fact that it is the local fibre volume fraction at the break that is significant. After post-curing the sheets for 3 hours at 80^{o}, they were cut into dog's-bone shaped specimens using a diamond saw and a 6-in dia. grinding wheel to give a reduced section 25mm x 5 mm over the central 40mm of the specimen. For fatigue testing, Instron 1272 servo-hydraulic machines were mainly used but a few long-term sine wave tests were done with a mechanical lever-arm machine incorporating a variable cam[1]. Static load tests were done either with conventional dead-weight cantilever creep rupture machines or in a bank of machines which loaded the specimens by means of a screw jack in series with a load cell.

3. Results and discussion

Results are shown in figs 1-6. The following points may be noted:-

1. There is a steady decrease in strength - of the order of ten percent per decade of time under static load and wet conditions (Fig 1). This is only about one half of that found for much thinner specimens in the form of impregnated strands[2].

2. In contrast to unidirectional specimens[2] and especially those in acid[1] there appears to be a real fatigue effect, in that the total time to failure under fatigue is less than that under static load. This is shown (a) by comparing times to failure under static load (Fig 1) with 0.1 Hz square wave fatigue (Fig 2) and 0.1 Hz sine wave (Fig 3) (b) by comparing 0.1 Hz sine wave (Fig 3) with 1.0 Hz sine wave (Fig 4) and (c) by the reduction in strength under dry fatigue (Fig 5) being greater than that found with unidirectional material in ref 2.

3. Despite the above, specimen lives are not purely dependent on the number of fatigue cycles. This is demonstrated by comparison of the 0.1 Hz and 1.0 Hz results, where a one decade shift in time does not entirely superimpose the experimental points.

4. The short term cracking stress, i.e. the "kink" in the conventional stress-strain curve was in the range 42-48 MN/m^2 corresponding to a cracking strain of 0.5%. Most of the experimental points are above this value and so it is possible that long term failure only takes place at strain greater than the initial cracking strain, particularly as the latter may be lower under fatigue loading.

5. The fall-off in strength in acid is greater than that in water but in this resin-rich system it is not as great as found previously[1]. Failure of chopped strand mat GRP under fatigue loading in wet conditions is thus a complex process with components of both stress corrosion and cycle-dependent fatigue, with specimen size and the resultant variation in diffusion paths providing a further complication. However although a fundamental understanding of the mechanism may not presently be feasible the practical need for methods of extrapolating short term data to predict long term properties remains. Clearly for such an extrapolation to have practical validity two conditions must be met: firstly the strength must tend towards a limiting value at short times, and secondly it must still be finite at long times. Hence plots of (linear) strength versus log time, (or cycles) which are often presented in the literature clearly do not satisfy either of these conditions and any linearity must be purely

fortuitous - perhaps being the central section of an 'S' shaped curve. A plausible straight line can often be drawn when the data (including our own) are plotted on a log strength - log time basis but this would not fulfill the first criterion.

The simplest general expression which meets both these conditions is of the form

$$t = \frac{K}{\sigma_a^n}\left(1 - \frac{\sigma_a}{\sigma_{max}}\right) \qquad (1)$$

where t is the time to failure, σ_a is the failure stress, σ_{max} the limiting strength at short times and K and n are constants. It is noteworthy that this is of the same form as equation (6) of reference (1) where in that case the constant n was the exponent of the crack growth law (for brittle failure where the crack propogates at right angles to the fibres) and K in the present case is a combination of other constants including an initial flaw size.

Transposing equation (1) and taking logs we get:-

$$\ln\left(\frac{1 - \sigma_a/\sigma_{max}}{t}\right) = n \ln \sigma_a - \ln K \qquad (2)$$

which represents a straight line when $\ln\left(\frac{1 - \sigma_a/\sigma_{max}}{t}\right)$ is plotted against $\ln \sigma_a$.

A linear least squares analysis was used to calculate the slope n and intercept - ln K. With a common value of $\sigma_{max} = 101$ MN/m^2, n and K were then used to obtain the curves shown in figs 1-6, where log σ_a is plotted against log t.

These curves (with only two adjustable parameters) fit the data just about as well as any freehand curve drawn without such constraints, and have the added advantage of not being entirely empirical.

In two cases which have been studied previously, i.e. an uncoupled bundle of glass fibres and unidirectional GRP in acid, where the fibres may be regarded as completely coupled, it has been predicted theoretically and found in practice that at long times a plot of log σ_a versus log t tended towards linearity at long times. The present case may be regarded as intermediate between these two extremes and so it is plausible that the same rule should apply.

References

1. Aveston, J., and Sillwood, J.M. NPL report DMA(A)39, 1982.
2. Aveston, J., Kelly, A. and Sillwood, J.M., Proc. of Third Int. Conf. on Composite Materials, Paris 1980.

Captions to figures

Fig. 1. Stress rupture of GRP in distilled water. Curve is calculated using equation (1) with $n = 16.6$ and $K = 1.44 \times 10^{36}$.

Fig. 2. Time to failure of GRP in distilled water under fatigue loading from zero to indicated stress, 0.1 Hz square wave. Curve is calculated using equation (1) with $n = 6.05$ and $K = 3.12 \times 10^{15}$.

Fig. 3. As Fig 2 but sine wave, $n = 7.86$ and $K = 1.4 \times 10^{19}$.

Fig. 4. As Fig 3 but 1.0 Hz $n = 9.76$ and $K = 6.16 \times 10^{21}$.

Fig. 5. As Fig 3 but dry (ambient) conditions.

n 8.75 and $K = 8.82 \times 10^{21}$

Fig. 6. Stress rupture of GRP in normal sulphuric acid. Curve is calculated from equation (1) with $n = 10.72$ and $K = 8.90 \times 10^{23}$.

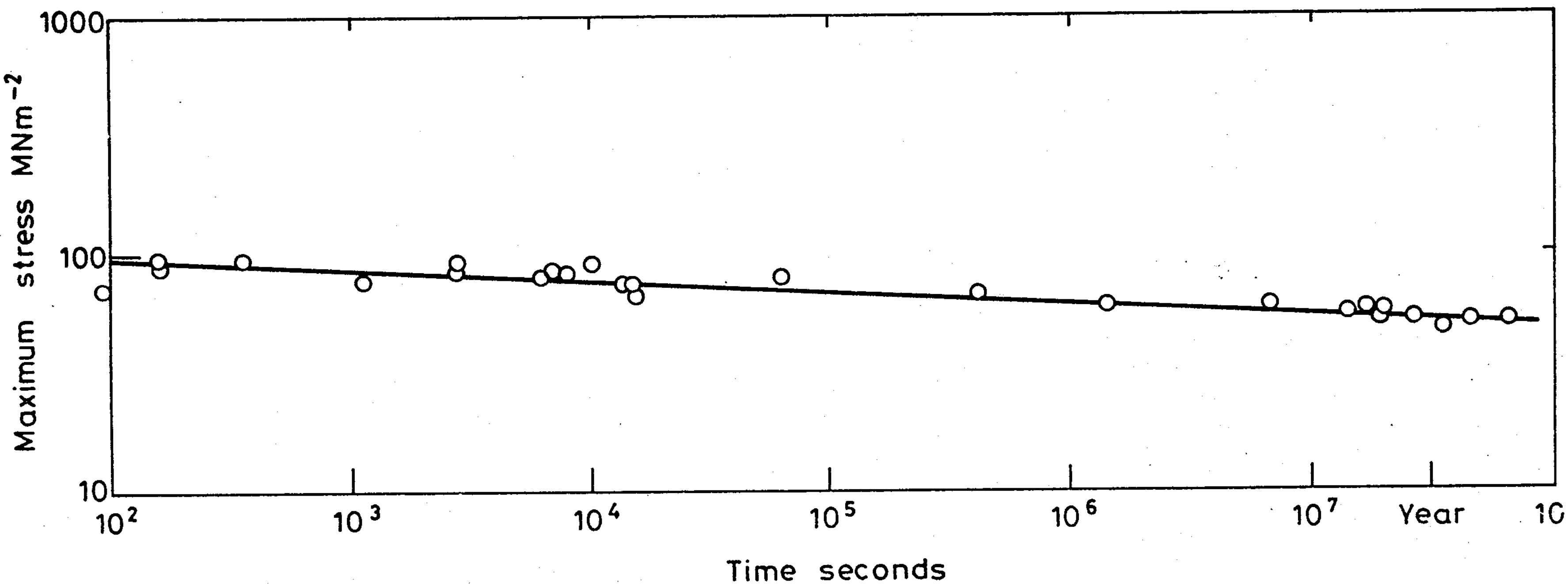

Fig 1 Stress rupture of GRP in distilled water. Curve is calculated using equation (1) with $n = 16 \cdot 6$ and $K = 1{\cdot}44 \times 10^{36}$

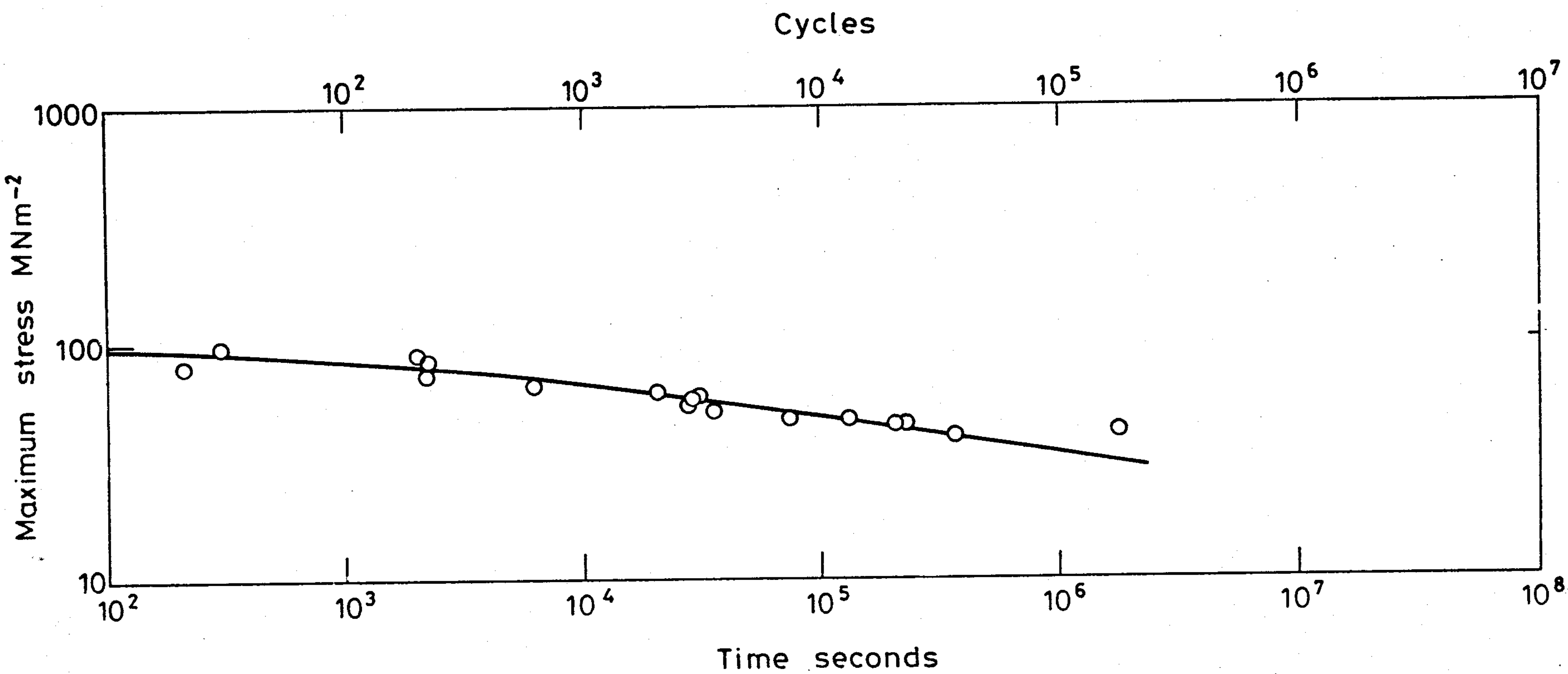

Fig 2 Time to failure of GRP in distilled water under fatigue loading from zero to indicated stress, 0·1 Hz square wave. Curve is calculated using equation (1) with $n = 6{\cdot}05$ and $K = 3{\cdot}12 \times 10^{15}$

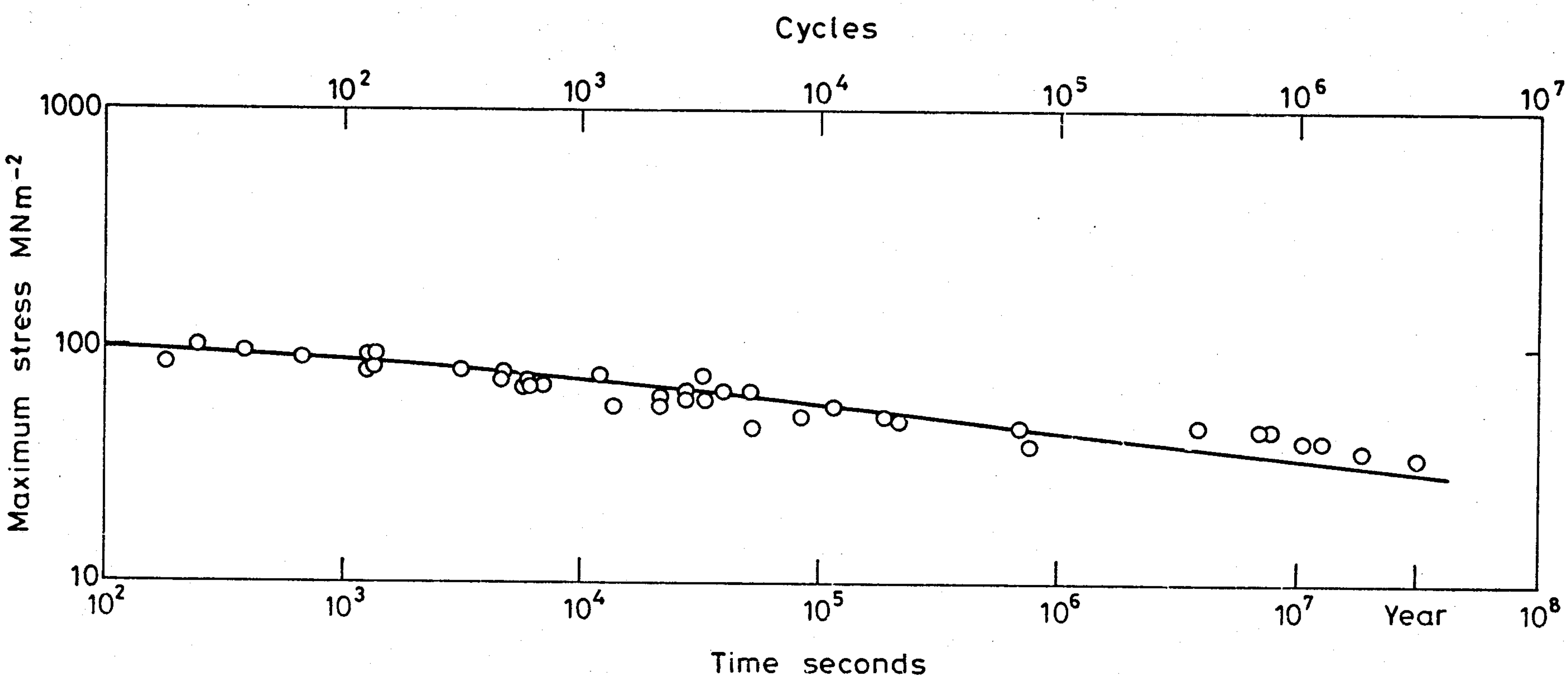

Fig 3 Time to failure of GRP in distilled water under fatigue loading from zero to indicated stress, 0·1 Hz sine wave. Curve is calculated using equation(1) with $n = 7{\cdot}86$ and $K = 1{\cdot}4 \times 10^{19}$

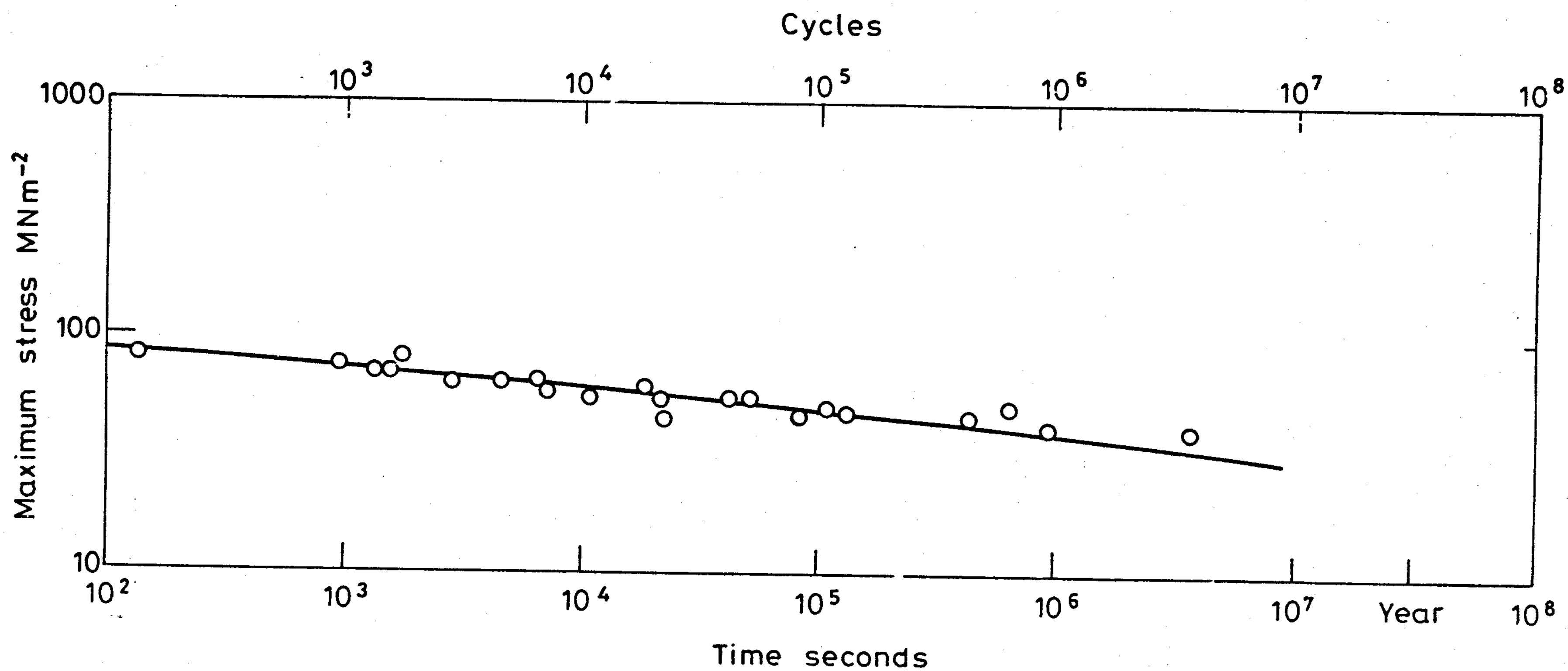

Fig 4 Time to failure of GRP in distilled water under fatigue loading from zero to indicated stress, 1·0Hz sine wave. Curve is calculated using equation(1) with $n = 9{\cdot}76$ and $K = 6{\cdot}16 \times 10^{21}$

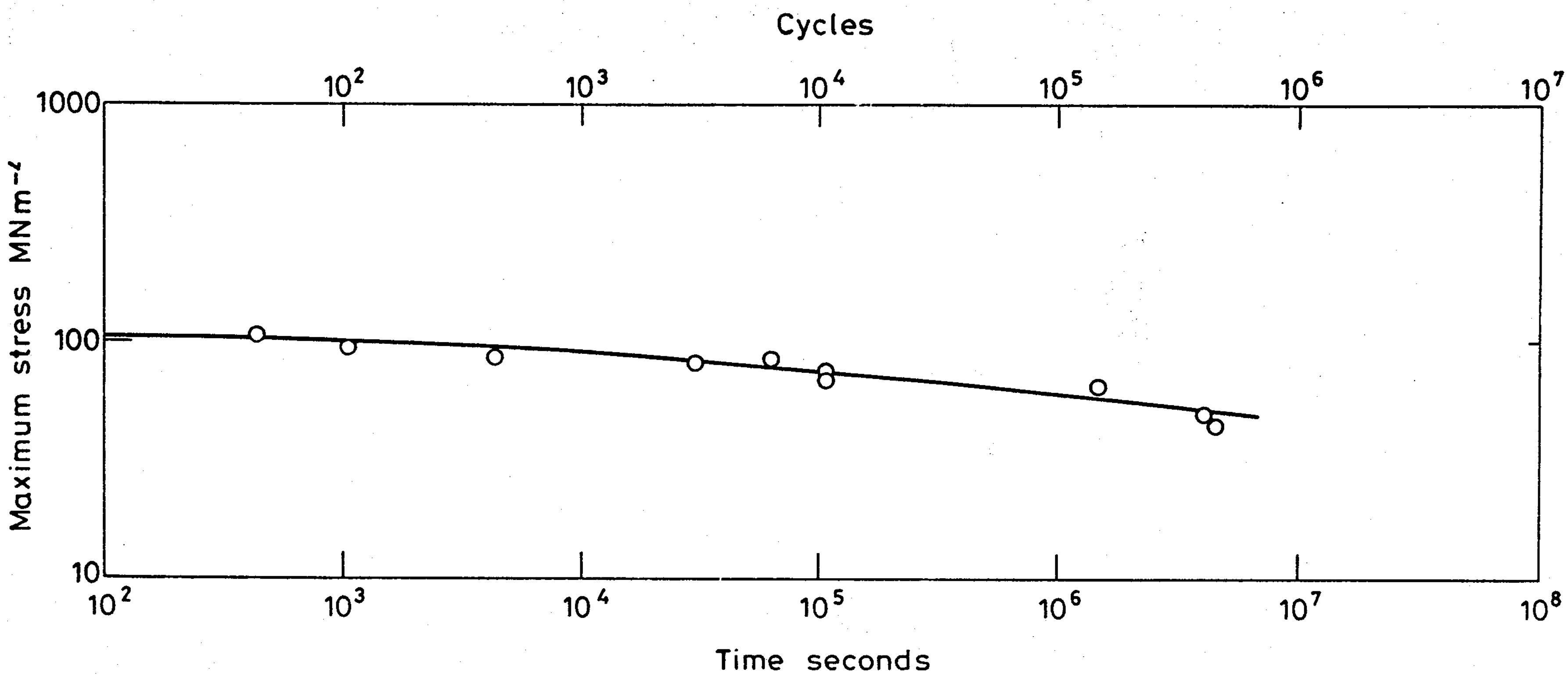

Fig 5 Time to failure of GRP in dry (ambient) conditions under fatigue loading from zero to indicated stress. Curve is calculated using equation (1) with $n = 8{\cdot}75$ and $K = 8{\cdot}82 \times 10^{21}$

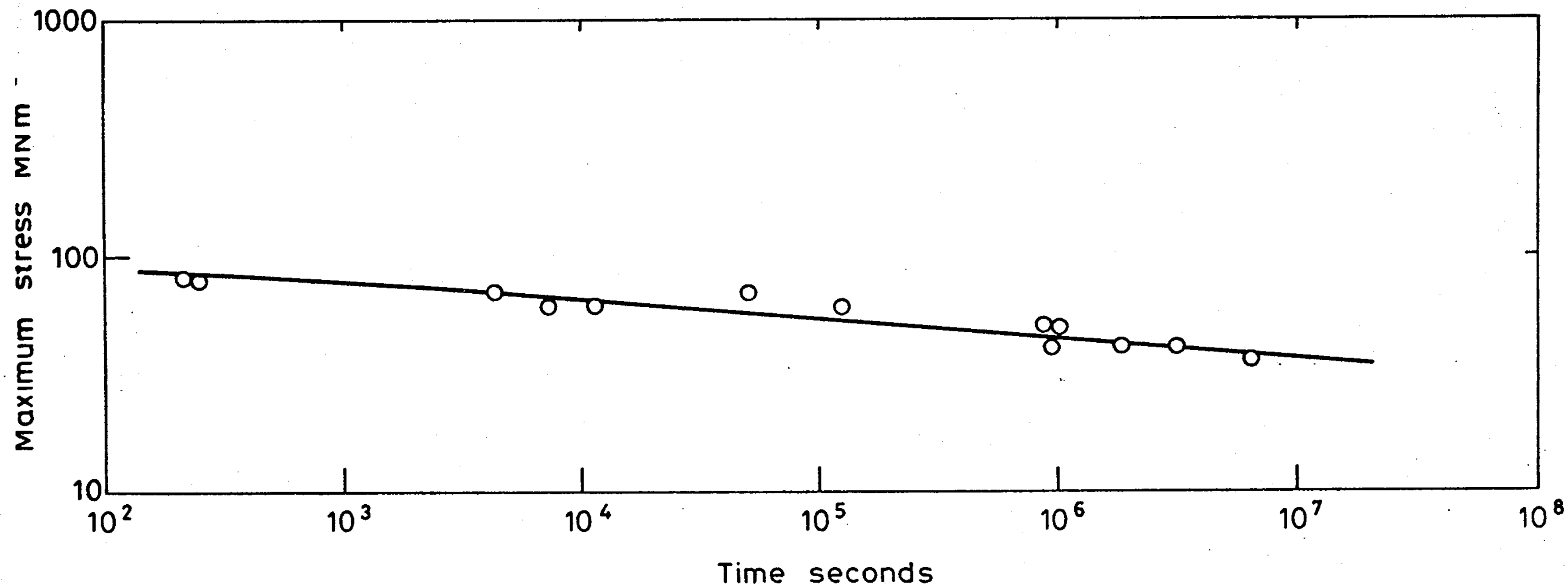

Fig 6 Stress rupture of GRP in normal sulphuric acid. Curve is calculated using equation (1) with

with $n = 10{\cdot}72$ and $K = 8{\cdot}90 \times 10^{23}$